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10. SUPERSONIC 2D WING WITH CONTROL SURFACES

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INTRODUCTION

For some years ONERA, in collaboration with AEROSPATIALE, has undertaken research into improvement of CFD codes, in the framework of studies on a new supersonic plane. The main goal has been to take unsteady effects, induced by movements of control surfaces such as spoilers or trailing edge flaps, into account with improved accuracy. For this purpose a wind tunnel test was carried out to provide an extensive database of unsteady behavior of control surfaces in supersonic conditions. ONERA has designed a generic 2D rigid model with two control surfaces: a spoiler and a trailing edge flap. These two control surfaces were moved in rotation by electro-hydraulic actuators, allowing an adjustment in static position as well as a harmonic excitation. A model with steady and unsteady pressure transducers, and accelerometers, was installed in the ONERA S2 wind tunnel at Modane in March 1994 (figures 1 and 2).

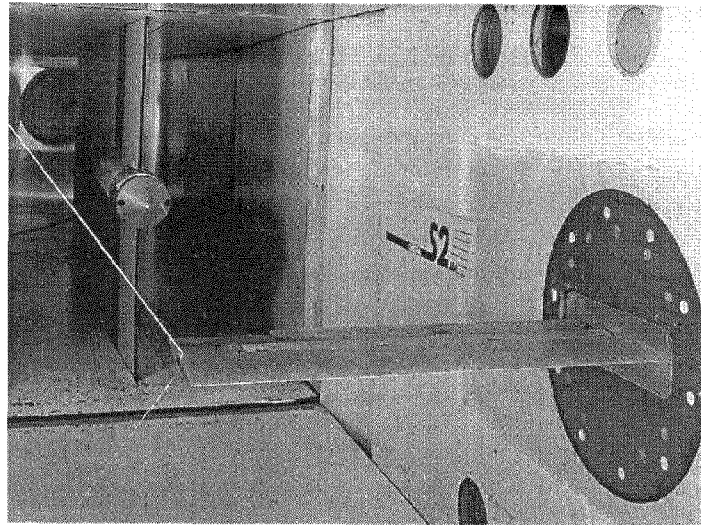


Figure 1: Model in the wind-tunnel section

LIST OF SYMBOLS AND DEFINITIONS

A	amplitude of harmonic excitation, (deg.)
α	angle of attack, alpha
β	deflection of the trailing edge flap, beta
c	wing chord
C_p	unsteady pressure coefficient $C_p = \frac{P_i \cdot e^{j(\omega_0 t + \phi_0)}}{Q_0 \cdot A}$
C_{pm}	mean pressure coefficient
C_{pq}	quasi-steady pressure coefficient $C_{pq} = \frac{C_{pm}(\beta + \Delta\beta) - C_{pm}(\beta - \Delta\beta)}{2 \cdot \Delta\beta}$
F	excitation frequency
M	Mach number
P_i	modulus of the unsteady pressure at excitation frequency ω_0
P_{i0}	stagnation pressure

Q0	dynamic pressure
R	Reynolds number referred to model chord (0.4 m)
Ti0	stagnation temperature
x/c	non-dimensional chord location

TESTING EQUIPMENT

MODEL

The model, a rectangular wing of 1.1 m span and 0.4 m chord was manufactured in aluminum alloy. Figure 3 shows general dimensions of the model. The airfoil had a biconvex symmetrical shape of 7 % relative thickness with a sharp leading edge as indicated in figure 4. Co-ordinates are shown in table 1 and in a separate file "airfoil.txt". The spoiler and trailing edge flap have chords, respectively, of 10% and 20% of the root chord. Spans of these control surfaces were limited in order to minimize their inertia and to preserve a good quality of the supersonic flow on the measured sections for the lower Mach number ($M = 1.65$).

In order to improve the dynamic behavior of the model, guys lines were connected to the middle of the wing tip (visible on the left side of the figure 1). A tension of 1500 N increased the first bending frequency by about 50 %.

Other details of the test apparatus are presented in the formulary.

INSTRUMENTATION

Instrumentation of the model consists of two pressure sections with 53 steady and unsteady pressure taps each. Details of span locations and chord distribution of these pressure taps are presented on figures 5 - 6 and table 2. Kulite transducers (type XCQI.093D) were used for unsteady pressure measurements. In order to obtain more accurate pressure measurements, pressure taps do not have the same layout on the lower and the upper surfaces. Pressure taps on upper surface are mainly put around the spoiler while they are concentrated near the flap hinge on the lower surface.

There was no steady deflection measurement of the model. Steady torsion was indirectly observed through Cpm distribution on the outside measurement section. This effect was almost non-existent on the mid-span section.

Dynamic deflection of the model was measured with 16 accelerometers, 6 on the spoiler, 4 on the flap and 6 on the fixed part. Locations of these accelerometers are shown on Figure 6 and Table 3.

Control surface motion was measured by two rotating potentiometers located on hydraulic actuator's shaft.

AVAILABLE DATA

Only measurements with trailing edge flap motion are provided in this data base, none relevant to the spoiler configuration are included. In order to limit the amount of data, a reduced number of representative data points has been chosen; these points and the corresponding test conditions are listed on table 4. The pressure data file "pressure.txt" includes steady, quasi-steady and unsteady pressure distributions on the mid-span section (upper and lower surface at $Y = 509$ mm). A self-explanatory listing of one data set is presented, with corresponding graphs, in the appendix. Accelerometer measurements are also included for all the selected points in a separate data file "accelero.txt".

CONTENTS OF NUMERICAL DATA FILES

The folder includes three ASCII data files. The file named 'airfoil.txt' contains the co-ordinates of the theoretical airfoil shape as presented in table 1 (Size = 2 KB).

The file named 'pressure.txt' contains all steady, quasi-steady and unsteady pressure measurements for the data points listed in table 4 (Size = 59 KB). An example of the format used is presented in the appendix; it is self-explanatory, and all symbols are listed above. Quasi-steady values were calculated from 2 steady measurements with 2 different flap deflections (+0.5 and -0.5 deg. from the indicated deflection). Quasi-steady distributions are comparable with unsteady Cp distribution modulus at low frequency.

Accelerometer measurements, and locations, are included in the file 'accelero.txt' (Size = 22 KB). The values presented correspond to the transfer function between acceleration and angle measured at the flap root. Two frequencies are presented, so there are two complex values, measured by accelerometer in $(m/s^2)/deg$.

FORMULARY

1 General Description of model

1.1	Designation	ONERA 2D Supersonic wing
1.2	Type	Generic model
1.3	Derivation	Model manufactured at ONERA
1.4	Additional remarks	None
1.5	References	1

2 Model Geometry

2.1	Planform	Rectangular
2.2	Aspect ratio	2.75
2.3	Leading edge sweep	0°
2.4	Trailing edge sweep	0°
2.5	Taper ratio	N/A
2.6	Twist	0°
2.7	Wing chord	400 mm
2.8	Semi-span of model	1100 mm
2.9	Area of planform	0.44 m ²
2.10	Definition of profiles	7 % supersonic airfoil, bi-convex symmetric sharp leading edge (see figure 4, table 1 and file "airfoil.txt" for co-ordinates)
2.11	Wing-body	None
2.12	Form of wing tip	Straight
2.14	Control surface details	2 rectangular control surfaces (flap and spoiler) (see figure 3 for positions and dimensions, and figure 4 for maximum steady amplitude)
2.15	Additional remarks	Two guys were fixed between the middle of the wing tip and the right side wall for improving dynamic behavior of the model. Tension in guys was about 1500 N. Attachment point on the model was on the rotating axis (see figure 1).

3 Wind Tunnel

3.1	Designation	ONERA S2 at Modane
3.2	Type of tunnel	Continuous, variable pressure
3.3	Test section dimensions	Height = 1.935 m, width = 1.75 m
3.4	Type of roof and floor	Solid
3.5	Type of side walls	Solid
3.6	Ventilation geometry	N/A
3.7	Thickness of side wall boundary layer	150 mm at model location (empty tunnel, for any Mach number)
3.8	Thickness of boundary layers at roof and floor	150 mm at model location (empty tunnel, for any Mach number)
3.9	Method of measuring velocity	Not Available
3.10	Flow angularity	Not Available
3.11	Uniformity of velocity over test section	Not Available
3.12	Sources and levels of noise or turbulence in empty tunnel	Not Available
3.13	Tunnel resonance's	Fan blade resonance's
3.14	Additional remarks	None

- | | | |
|------|----------------------|------|
| 3.15 | References on tunnel | None |
|------|----------------------|------|

4 Model motion

- | | | |
|-----|--|---|
| 4.1 | General description | Steady incidence about an axis normal to wind tunnel side-wall located on the middle of root chord. |
| 4.2 | Natural frequencies and normal modes of model and support system | First bending mode at 37 Hz, torsion at 76.9 Hz, second bending mode at 96.3 Hz (with the tensioned guy lines). The values of excitation frequencies have been chosen between modal frequencies in order to avoid dynamic deformation of the wing. Only rotation of the trailing edge has to be taken into account in CFD simulations. Acceleration measurements are provided to check that dynamic motion of the wing is negligible. |

5 Test Conditions

- | | | |
|------|---|---|
| 5.1 | Model planform area/tunnel area | 13 % |
| 5.2 | Model span/tunnel width | 62.86 % |
| 5.3 | Blockage | 1.2 % max. |
| 5.4 | Position of model in tunnel | Model fixed on a wall turret on the left side wall |
| 5.5 | Range of Mach number | 1.65, 2.0, 2.5 |
| 5.6 | Range of tunnel total pressure | 0.9 bar |
| 5.7 | Range of tunnel total temperature | 300 K |
| 5.8 | Range of model steady or mean incidence | -2, 0, +2 deg. |
| 5.9 | Definition of model incidence | model incidence defined relative to horizontal wind tunnel axis |
| 5.10 | Position of transition, if free | Not available |
| 5.11 | Position and type of strip, if transition fixed | Free transition (no transition strip). |
| 5.12 | Flow instabilities during tests | Not available |
| 5.13 | Changes to mean shape of model due to steady aerodynamic load | Not measured |
| 5.14 | Additional remarks | None |
| 5.15 | References describing tests | 1 |

6 Measurements and Observations

- | | | |
|------|---|------|
| 6.1 | Steady pressures for the mean conditions | Yes |
| 6.2 | Steady pressures for small changes from the mean conditions | Yes |
| 6.3 | Quasi-steady pressures | Yes |
| 6.4 | Unsteady pressures | Yes |
| 6.5 | Steady section forces for the mean conditions by integration of pressures | No |
| 6.6 | Steady section forces for small changes from the mean conditions by integration | No |
| 6.7 | Quasi-steady section forces by integration | No |
| 6.8 | Unsteady section forces by integration | No |
| 6.9 | Measurement of dynamic motion at points of model | Yes |
| 6.10 | Observation or measurement of boundary layer properties | No |
| 6.11 | Visualisation of surface flow | No |
| 6.12 | Visualisation of shock wave movements | No |
| 6.13 | Additional remarks | None |

7 Instrumentation

7.1	Steady pressure	2 sections with 53 taps each (total number 106)
7.1.1	Position of orifices spanwise and chordwise	Sections were located at Y= 504 and 704 mm. For each section there was 29 taps on the upper surface and 24 taps on the lower surface (see figure 5 and table 2 for locations).
7.1.2	Type of measuring system	PSI system
7.2	Unsteady pressure	2 sections with 53 pressure transducers each (total number 106)
7.2.1	Position of orifices spanwise and chordwise	Sections were located at Y= 509 and 709 mm. Chordwise layout is the same than steady pressure taps (see figure 4 and table 2 for locations).
7.2.2	Diameter of orifices	0.8 mm
7.2.3	Type of measuring system	ONERA's conditioners and amplifiers
7.2.4	Type of transducers	Kulite XCQL 093 5D
7.2.5	Principle and accuracy of calibration	Calibrated in situ with an harmonic pressure generator.
7.3	Model and control surfaces motion	
7.3.1	Method of measuring motion reference co-ordinate	Rotating potentiometer
7.3.2	Method of determining spatial mode of motion	16 accelerometers: 6 on the spoiler, 4 on the flap and 6 on the fixed part. Locations of these accelerometers are shown in Fig. 6 and Table 3
7.3.3	Accuracy of measured motion	0.01° (angle measurement with potentiometer)
7.4	Processing of unsteady measurements	
7.4.1	Method of acquiring and processing measurements	Sampling frequency was 32 times the frequency of the sinusoidal excitation
7.4.2	Type of analysis	Real time FFT
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Cp referenced to control surface motion
7.4.4	Method of integration to obtain forces	N/A
7.5	Additional remarks	Accelerometers measurements in file "accelero.txt"
7.6	References on techniques	None

8 Data presentation

8.1	Test cases for which data could be made available	---
8.2	Test cases for which data are included in this document	See Table 4
8.3	Steady pressures	See file "pressure.txt"
8.4	Quasi-steady or steady perturbation pressures	See file "pressure.txt"
8.5	Unsteady pressures	See file "pressure.txt" (2 frequencies)
8.6	Steady forces or moments	No
8.7	Quasi-steady or unsteady perturbation forces	No
8.8	Unsteady forces and moments	No
8.9	Other forms in which data could be made available	None
8.10	Reference giving other representations of data	None

9 Comments on data

9.1	Accuracy
-----	----------

9.1.1 Mach number	$\pm 0.001 M$
9.1.2 Steady incidence	$\pm 0.01 \text{deg}$
9.1.3 Reduced frequency	Not Available
9.1.4 Steady pressure coefficients	Better than $\pm 0.002 \text{ Cpm}$
9.1.5 Steady pressure derivatives	Not Available
9.1.6 Unsteady pressure coefficients	Not Available
9.2 Sensitivity to small changes of parameter	Not Available
9.3 Non-linearities	Not Available
9.4 Influence of tunnel total pressure	N/A (Constant pressure 0.9 bar)
9.5 Effects on data of uncertainty, or variation, in mode of model motion	Not Available
9.6 Wall interference corrections	Not Available
9.7 Other relevant tests on same model	None
9.8 Relevant tests on other models of nominally the same shapes	None
9.9 Any remarks relevant to comparison between experiment and theory	None
9.10 Additional remarks	None
9.11 References on discussion of data	N/A

10 Personal contact for further information

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11 List of references

- 1 P. Naudin, Résultats d'essais d'une maquette bi-dimensionnelle munie d'un spoiler et d'une gouverne en supersonique. Avril 1996 ONERA Report n° 24/5115RN031R

x/c	z/c	x/c	z/c	x/c	z/c
0	0	.38	3.232093E-02	.66	3.311437E-02
.02	5.966748E-03	.4	.0328363	.68	3.231008E-02
.04	9.564082E-03	.42	3.330968E-02	.7	3.138345E-02
.06	1.263181E-02	.44	3.374017E-02	.72	3.021743E-02
.08	1.534582E-02	.36	3.175883E-02	.74	2.896985E-02
.1	1.771105E-02	.38	3.232093E-02	.76	2.747098E-02
.12	1.972565E-02	.4	.0328363	.78	.0258573
.14	2.148475E-02	.42	3.330968E-02	.8	2.406145E-02
.16	2.299185E-02	.44	3.374017E-02	.82	2.209795E-02
.18	.0243222	.46	3.412692E-02	.84	2.001825E-02
.2	2.549977E-02	.48	.0344435	.86	1.775008E-02
.22	2.654872E-02	.5	3.469358E-02	.88	1.542041E-02
.24	2.748777E-02	.52	.0348817	.9	1.292678E-02
.26	2.833828E-02	.54	3.498145E-02	.92	1.041014E-02
.28	2.911947E-02	.56	3.496132E-02	.94	7.797632E-03
.3	.0298445	.58	3.485948E-02	.96	5.181032E-03
.32	3.052228E-02	.6	3.463373E-02	.98	2.590508E-03
.34	3.115928E-02	.62	.0342517	1	0
.36	3.175883E-02	.64	3.378113E-02		

Table 1: Theoretical airfoil co-ordinates

Upper Surface		Lower Surface	
X from L.E.(mm)	X/C (%)	X from L.E.(mm)	X/C (%)
20	5	20	5
40	10	40	10
60	15	60	15
80	20	80	20
100	25	100	25
120	30	120	30
140	35	140	35
152	38	164	41
160	40	188	47
168	42	212	53
175	43.75	236	59
182	45.5	260	65
188	47	272	68
194	48.5	284	71
204	51	294	73.5
212	53	304	76
220	55	312	78
228	57	326	81.5
236	59	335	83.75
244	61	344	86
252	63	353	88.25
260	65	362	90.5
268	67	371	92.75
276	69	380	95
284	71		
304	76		
326	81.5		
344	86		
362	90.5		

Table 2: Locations of unsteady pressure taps for sections at Y= 509 or 709 mm

	Nbr Accelero.	X from L.E.(mm)	X/C (%)	Y from root (mm)
Wing	1	80	20	242
	4	300	75	242
	7	80	20	542
	10	300	75	542
	13	80	20	948
	16	300	75	948
Flap	2	208	52	242
	3	234	58.5	242
	8	208	52	542
	9	234	58.2	542
	14	208	52	948
	15	234	58.2	948
Spoiler	5	336	84	242
	6	380	95	242
	11	336	84	542
	12	380	95	542

Table 3: Locations of accelerometers

Mach	Steady Angle of attack	Flap Deflection	Run Number	Steady Measur.	Quasi.- steady	1 st Unsteady freq. (Hz)	2 nd Unsteady freq. (Hz)
1.65	$\alpha_1 = -2^\circ$	$\beta_1 = 0^\circ$	301	x	x	60 (A=0.5)	125 (A=0.3)
	$\alpha_2 = 0^\circ$	$\beta_1 = 0^\circ$	305	x	x	60 (A=0.5)	130 (A=0.15)
		$\beta_2 = 2^\circ$	310	x	x	60 (A=0.5)	130 (A=0.2)
		$\beta_3 = 4^\circ$	313	x	x	70 (A=0.5)	130 (A=0.2)
	$\alpha_3 = 2^\circ$	$\beta_1 = 0^\circ$	317	x	x	70 (A=0.5)	130 (A=0.2)
2.0	$\alpha_2 = 0^\circ$	$\beta_1 = 0^\circ$	342	x	x	60 (A=0.5)	130 (A=0.2)
		$\beta_2 = 2^\circ$	348	x	x	60 (A=0.5)	130 (A=0.2)
		$\beta_3 = 4^\circ$	353	x	x	60 (A=0.5)	130 (A=0.2)
	$\alpha_3 = 2^\circ$	$\beta_1 = 0^\circ$	327	x	x	60 (A=0.5)	130 (A=0.2)
		$\beta_2 = 2^\circ$	332	x	x	60 (A=0.5)	130 (A=0.2)
2.5	$\alpha_2 = 0^\circ$	$\beta_1 = 0^\circ$	391	x	x	60 (A=0.5)	120 (A=0.2)
		$\beta_2 = 2^\circ$	397	x	x	60 (A=0.5)	120 (A=0.2)
		$\beta_3 = 4^\circ$	402	x	x	60 (A=0.5)	120 (A=0.2)
	$\alpha_3 = 2^\circ$	$\beta_1 = 0^\circ$	407	x	x	60 (A=0.5)	120 (A=0.2)
		$\beta_2 = 2^\circ$	412	x	x	60 (A=0.5)	120 (A=0.2)

Table 4: List of selected data points

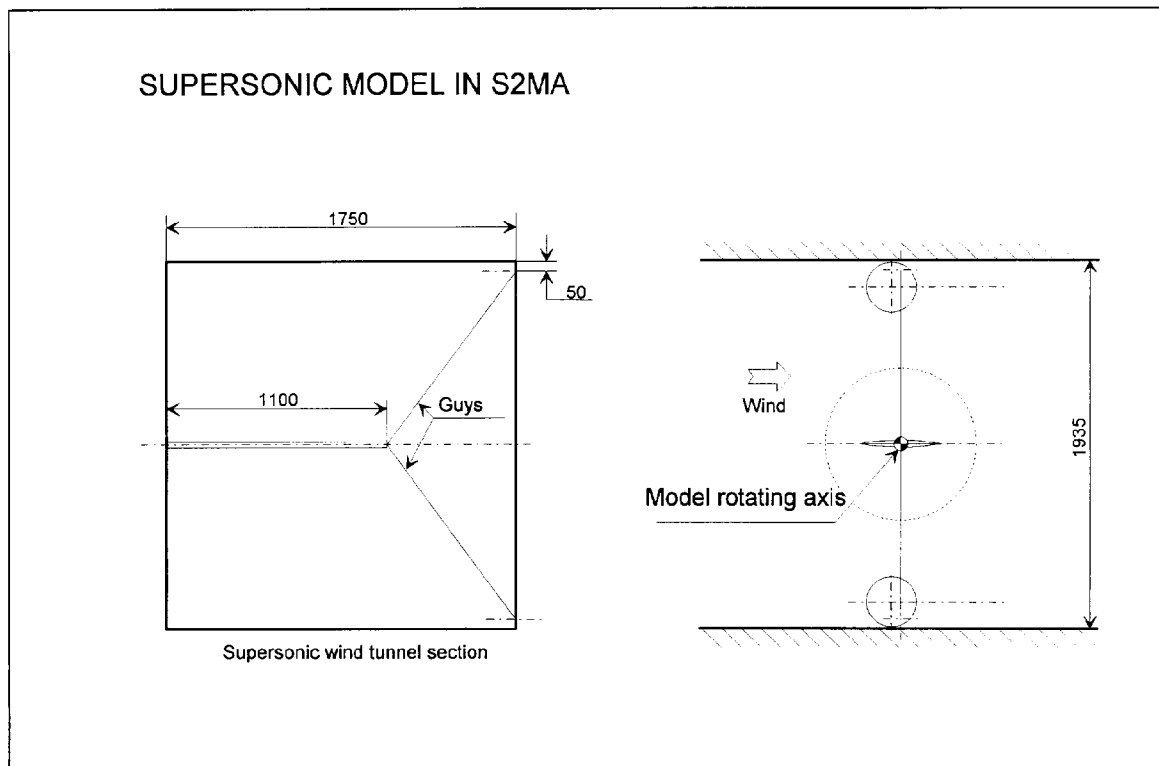


Figure 2: Dimensions of the wind-tunnel test section

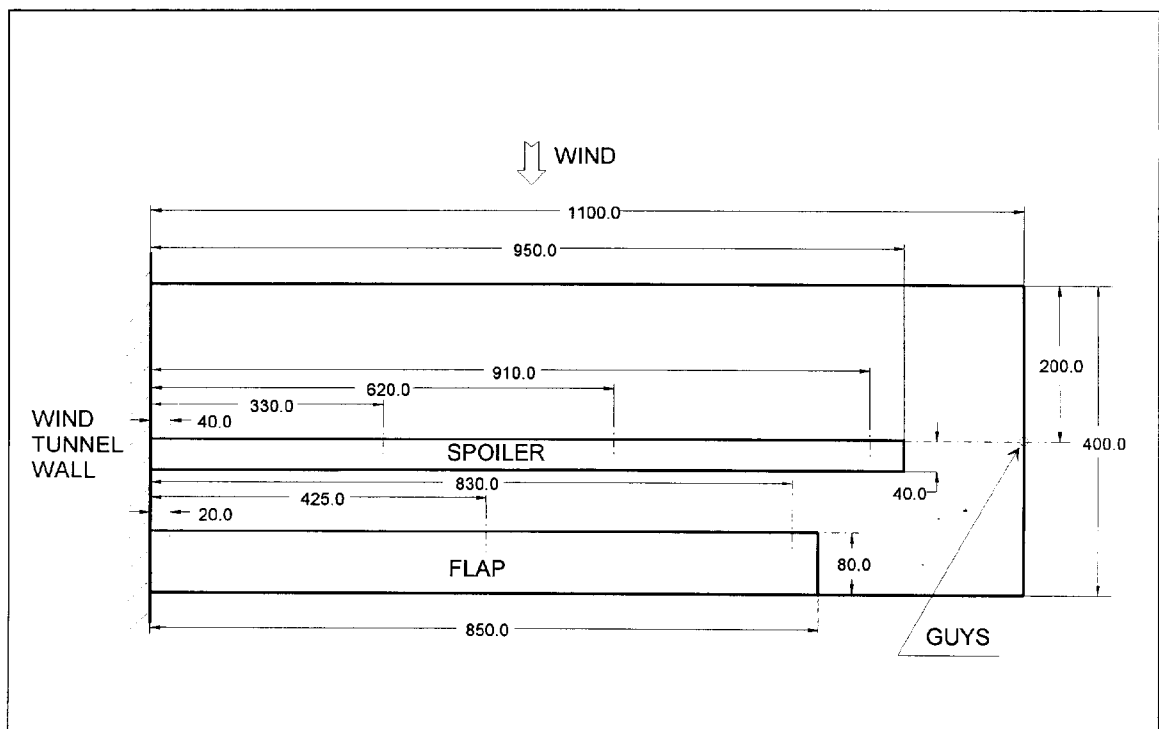


Figure 3: Dimensions of the model

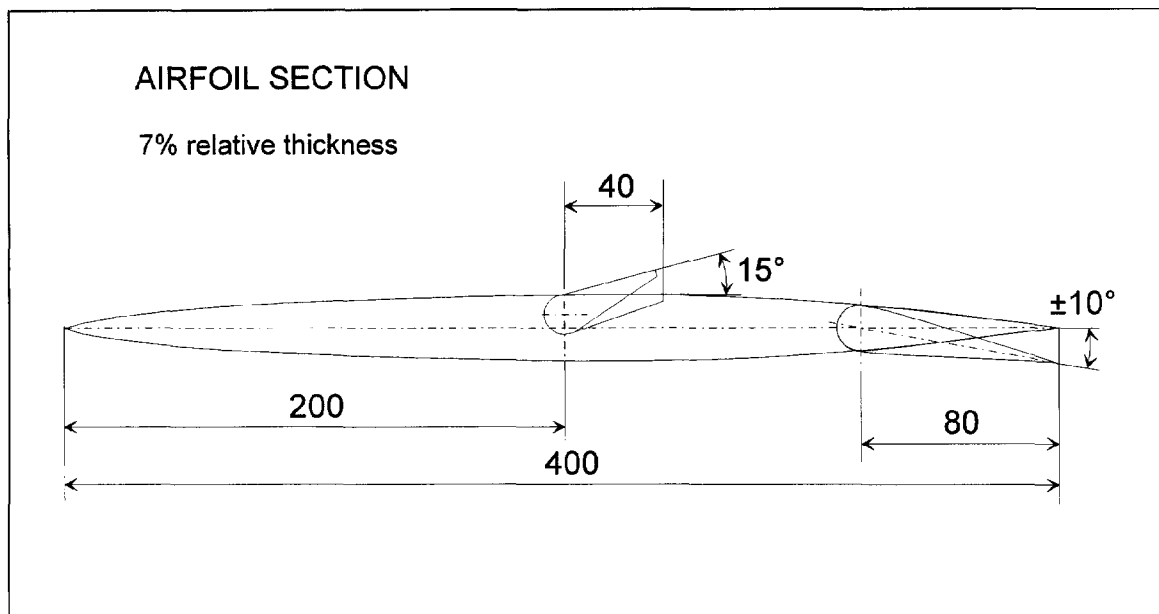


Figure 4: Airfoil and control surfaces

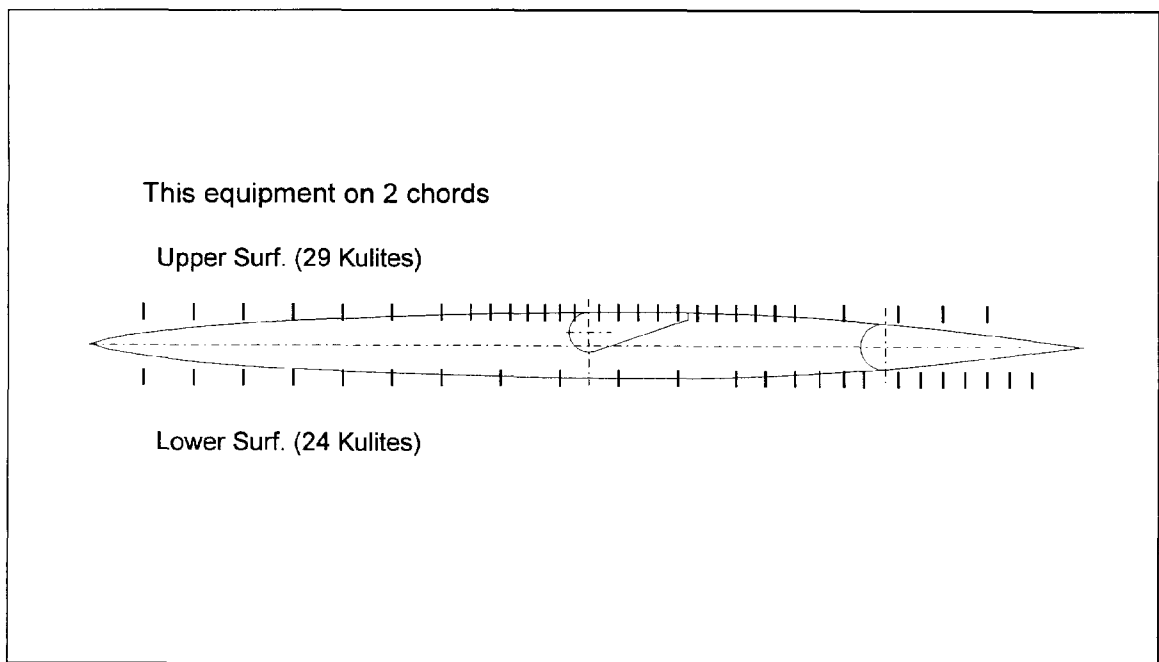


Figure 5: Transducers location

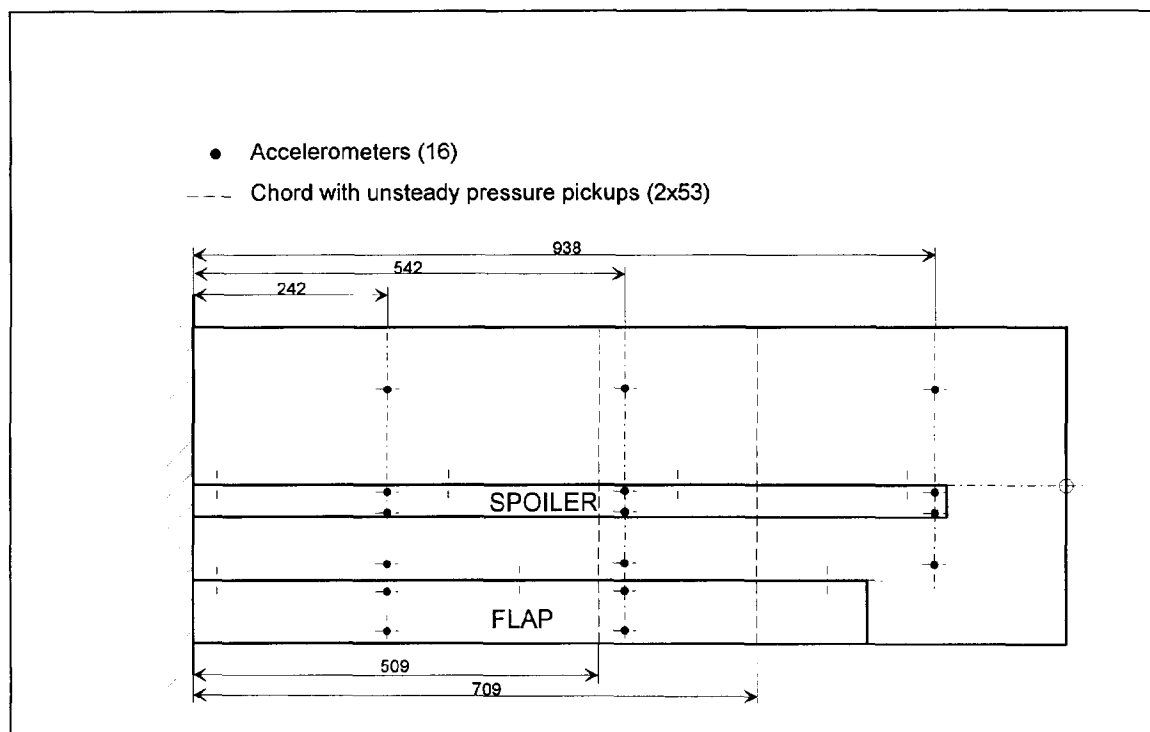


Figure 6: Placement of unsteady transducers

APPENDIX

Hereafter, an example of the formatted data file 'pressure.txt'. This part of file shows data relative to Run N° 305 (M= 1.65, alpha= 0, beta= 0). Steady and unsteady pressure coefficients distribution for this run are presented in Figures 7, 8 and 9.

Run= 305

M= 1.649 Pi0(Pa)= 89943 Ti0(K)= 299.83 Q0(Pa)= 37447.1

R= 5.04 million alpha(deg.)= 0.008 beta(deg.)= -0.020

Upper Surface

x/c	Cpm	Cpq	F:60 Hz A:0.5		F:130 Hz A:0.15	
			Re (Cp)	Im (Cp)	Re (Cp)	Im (Cp)
0.0500	-0.3018	0.0535	0.0189	0.0037	0.0786	-0.0108
0.1000	-0.1983	0.1083	0.0166	-0.0146	0.0316	0.0011
0.1500	-0.1393	0.0403	0.0145	-0.0032	0.1115	0.0033
0.2000	-0.1023	0.0764	0.0193	-0.0050	0.0460	-0.0048
0.2500	-0.0792	0.0116	0.0157	0.0006	0.0561	-0.0275
0.3000	-0.0641	0.0496	0.0085	0.0004	0.0640	-0.0153
0.3500	-0.0563	0.0729	0.0123	-0.0019	0.0479	-0.0151
0.3800	-0.0547	0.0328	0.0123	-0.0077	0.0569	0.0004
0.4000	-0.0553	0.1448	0.0180	-0.0088	0.0469	-0.0122
0.4200	-0.0505	0.0647	0.0215	-0.0040	0.0309	0.0001
0.4375	-0.0508	-0.0172	0.0198	-0.0011	0.0462	0.0007
0.4550	-0.0473	0.0073	0.0161	-0.0029	0.0641	0.0119
0.4700	-0.0429	0.0400	0.0142	-0.0015	0.0483	0.0044
0.4850	-0.0288	0.0071	0.0130	-0.0023	0.0405	0.0270
0.5100	-0.0146	0.0295	0.0123	0.0048	0.1255	-0.0270
0.5300	-0.0102	0.0047	0.0138	0.0002	0.0996	-0.0165
0.5500	-0.0254	0.0136	0.0092	-0.0044	0.1223	0.0030
0.5700	-0.0233	0.0302	0.0032	-0.0108	-0.0063	-0.1106
0.5900	-0.0081	-0.0601	0.0109	-0.0046	0.1268	0.0099
0.6100	0.0149	0.0350	0.0087	-0.0148	-0.0320	-0.0291
0.6300	0.0219	0.0347	0.0110	-0.0137	-0.0352	-0.0225
0.6500	0.0390	0.0330	0.0132	-0.0134	-0.0506	-0.0261
0.6700	0.0433	0.0881	0.0108	-0.0103	-0.0159	-0.0291
0.6900	0.0548	0.0156	0.0102	-0.0109	-0.0001	-0.0338
0.7100	0.0721	-0.0550	0.0078	-0.0131	-0.0153	-0.0366
0.7600	0.1009	-0.0197	0.0019	-0.0148	-0.0011	-0.0345
0.8150	0.1388	-0.8926	-1.0267	-0.0237	-3.3390	0.1980
0.8600	0.1449	-0.9555	-1.0544	0.0238	-3.3092	0.4860
0.9050	0.1428	-0.9722	-1.0674	0.0176	-3.2185	0.3293

Lower Surface

x/c	Cpm	Cpq	F:60 Hz A:0.5		F:130 Hz A:0.15	
			Re (Cp)	Im (Cp)	Re (Cp)	Im (Cp)
0.0500	-0.3093	-0.0078	-0.0178	0.0005	-0.0861	-0.0276
0.1000	-0.2001	-0.0211	-0.0184	0.0015	-0.0837	0.0177

0.1500	-0.1347	-0.0097	-0.0220	0.0136	-0.0817	-0.0134
0.2000	-0.1009	0.0290	-0.0095	0.0060	-0.0849	-0.0212
0.2500	-0.0767	0.0345	-0.0075	0.0005	-0.0697	-0.0244
0.3000	-0.0620	0.0496	-0.0016	0.0029	-0.0639	-0.0019
0.3500	-0.0549	-0.0220	-0.0111	0.0045	-0.0463	0.0054
0.4100	-0.0445	-0.0240	-0.0133	0.0061	-0.0711	-0.0081
0.4700	-0.0376	-0.0174	-0.0073	-0.0004	-0.0643	-0.0270
0.5300	-0.0211	-0.0566	-0.0100	0.0048	-0.0748	-0.0228
0.5900	0.0003	-0.0413	-0.0123	0.0056	-0.0496	0.0007
0.6500	0.0289	0.0338	-0.0204	-0.0114	-0.0699	-0.0728
0.6800	0.0425	-0.0004	-0.0124	-0.0112	-0.0504	-0.0833
0.7100	0.0642	0.0162	-0.0110	-0.0115	-0.0637	-0.0670
0.7350	0.0771	-0.0033	-0.0113	-0.0100	-0.0556	-0.0646
0.7600	0.0872	0.0134	-0.0121	-0.0108	-0.0446	-0.0745
0.7800	0.0990	0.0034	-0.0134	-0.0127	-0.0501	-0.0814
0.8150	0.1336	0.8978	1.0383	-0.0236	3.3105	-0.3136
0.8375	0.1391	1.0306	1.0813	-0.0497	3.3478	-0.4582
0.8600	0.1428	0.9907	1.0888	-0.0709	3.2548	-0.5421
0.8825	0.1459	1.0320	1.1130	-0.0456	3.2976	-0.3863
0.9050	0.1507	0.9905	1.1055	-0.0051	3.3169	-0.1975
0.9275	0.1523	0.9821	1.0826	-0.0453	3.1006	-0.3928
0.9500	0.1570	1.0509	1.1165	0.0210	3.2651	-0.0127

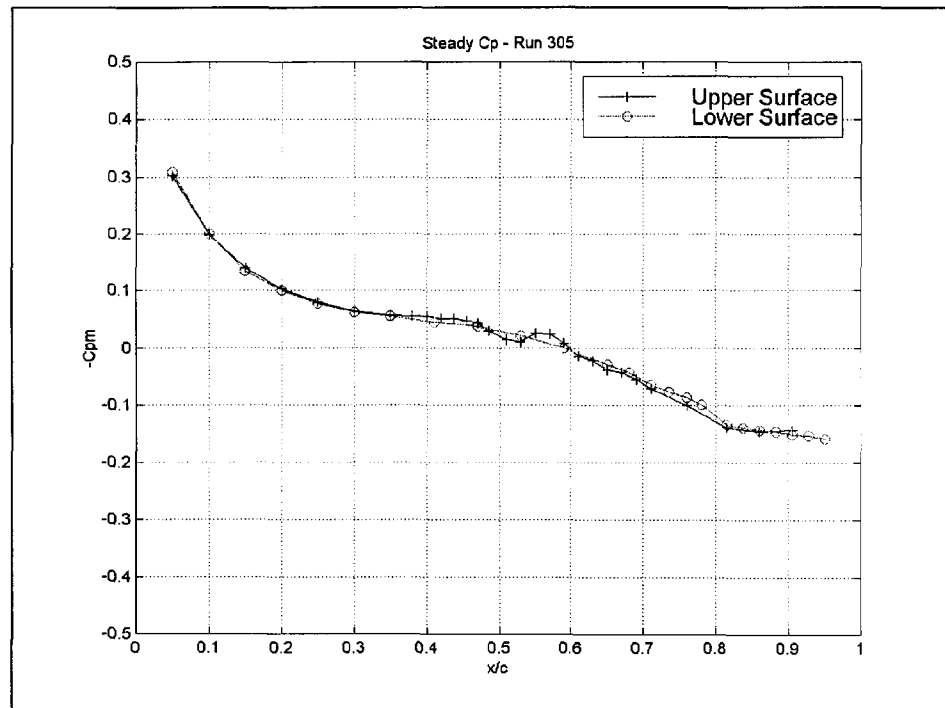


Figure 7

